International Journal of Engineering Education Vol. 29, No. 4, pp. 1024–1036, 2013
Printed in Great Britain

0949-149X/91 $3.00+0.00

Constructivist Game-based Robotics Simulator in Engineering Education*

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The aim of this study was to assess the learning environment of a constructivist game-based robotics simulator in engineering education as compared with a similar non game-based conventional robotics simulator. It was assessed in terms of students' perceptions of the simulation-based environment and attitudes toward robotics lessons using simulation. This study employed a quantitative method via two questionnaires: the six scales of Constructivist Simulation-based Learning Environment Survey (CSLES) and the one scale of Test of Robotics Related Attitudes (TORRA). The sample consisted of 114 undergraduate and fresh graduate students (age 22 to 25) who had attended a formal course of automation and robotics. They were randomly assigned into two groups: the experimental group ($n = 60$) and control group ($n = 54$). The experimental group used a game-based robotics simulator (G-IRSTS) and the control group used a conventional robot simulator (IRSTS). Using statistical methods, both CSLES and TORRA were found to exhibit good factor and reliability validity. The main finding of this study indicates that G-IRSTS is more effective than IRSTS in terms of Negotiation, Inquiry learning, Reflective Thinking and Challenge.

Keywords: constructivist learning; game-based learning; robot simulation, student perceptions

1. Introduction

Game-based learning has been used to support training and learning in various areas such as mechanical engineering [1], mechanics [2], manufacturing [3], computer-aided design [4], civil engineering [5], construction [6], software engineering [7–8], computer networks [9], computer programming [10] and natural science [11–12]. More importantly, it has been proven to have a great impact on the students learning [1–20]. Game-based learning improves the students' learning effectiveness [1, 14–15]. It stimulates students' motivation [11, 12, 16–18], engages students [2] and enhances the creative perception of students [20]. In addition, it significantly promotes the spatial abilities [19], flow experience, learning attitudes and technology acceptance of students [11].

Today, the robotics simulation tools that have been introduced are oriented to professional application. Generally these tools are developed for research purposes or industrial applications. There is no doubt that these tools are being used in education. Nevertheless, there are some simulation tools that have been developed mainly for education purposes such as RoboWorks [21], VirtualRobot System [22] and Virtual Robot Tutorial Software [23]. In general, these simulation tools provide a virtual environment for students to construct, configure or assemble various types of virtual robots on the computer screen. It allows students to visualize, navigate and test the virtual robots in different views. Different parameters of kinematics, dynamics, trajectories and control models can be edited and tested in most of the simulation tools. Virtual robots can be constructed for various applications and simulations can be run an unlimited number of times until the students are satisfied and fully understand the concepts behind it. Some of the tools had some special capabilities such as off-line programming and portable to a network. It can be seen that the role of the simulation tools was intended for use in constructivist pedagogy, which embraces the philosophy of considering the essential role of experience in knowledge construction, and places a more important role on student autonomy in the learning process.

Viknashvaran *et al.* [24] and Sauvé *et al.* [25] revealed that games and simulations are distinctive concepts. Games differ from simulation in term of goal orientation in which there are some objectives and a series of tasks to be completed by users in each scenario. Thereby, games are governed by rules that structure their actions. The structure introduces conflicts or obstacles, which prevent students from achieving their goals easily. Conflicts also include the notions of struggle, competition and challenge. These attributes always engage students, make

* Accepted 1 April 2013

learning fun, encourage dialogue between students and motivate students to maintain their gaming role or proceed to the next stage or different scenarios. The more stages or scenarios to be completed, the more points to be rewarded. The attributes are called the game elements.

This study aimed at assessing the learning environment of a constructivist game-based robotics simulator (G-IRSTS) in engineering education in terms of the students' perceptions of the simulation-based environment and their attitudes toward robotics lessons using simulation. G-IRSTS was designed on the basis of specific objectives and subject matter pertaining to the design and manufacturing of programs, as compared with a similar conventional non-gaming robotics simulator (IRSTS). In addition, this study included determining if there are associations between a simulation-based learning environment and attitudes toward robotics lessons with simulations in IRSTS and G-IRSTS, respectively.

2. Methods

2.1 Research design and questions

This study compared two simulation tools on robotics learning. Both simulation tools provided the same learning objectives, contexts, learner specification, pedagogical and similar modes of representations. The only difference was that one followed a gaming approach, whereas the other did not. The students that participated in the research were assigned to two groups, one of which used G-IRSTS (experimental group) and the other used IRSTS (control group). This research employed a quantitative method via two questionnaires: the six scales of Constructivist Simulation-based Learning Environment Survey (CSLES) and the one scale of Test of Robotics Related Attitude (TORRA). Based on the overview of the research literature, the research questions were formulated as follows.

- Are the simulation-based learning environment scales based on the CSLES and an attitude scale based on TORRA valid when used with the samples of engineering students in the control and experimental group respectively?
- Are there actual-preferred differences in the simulation-based learning environments in the control and experimental groups? Are there differences between the control group and the experimental group in terms of their perceptions of the same actual simulation-based learning environments, their preferred simulation-based learning environments, and attitudes toward robotics lessons using simulations?
- Are there associations between the students' attitudes toward robotics lessons using simulation and their perceptions of the simulation-based learning environment in the control and experimental groups?

2.2 Participants

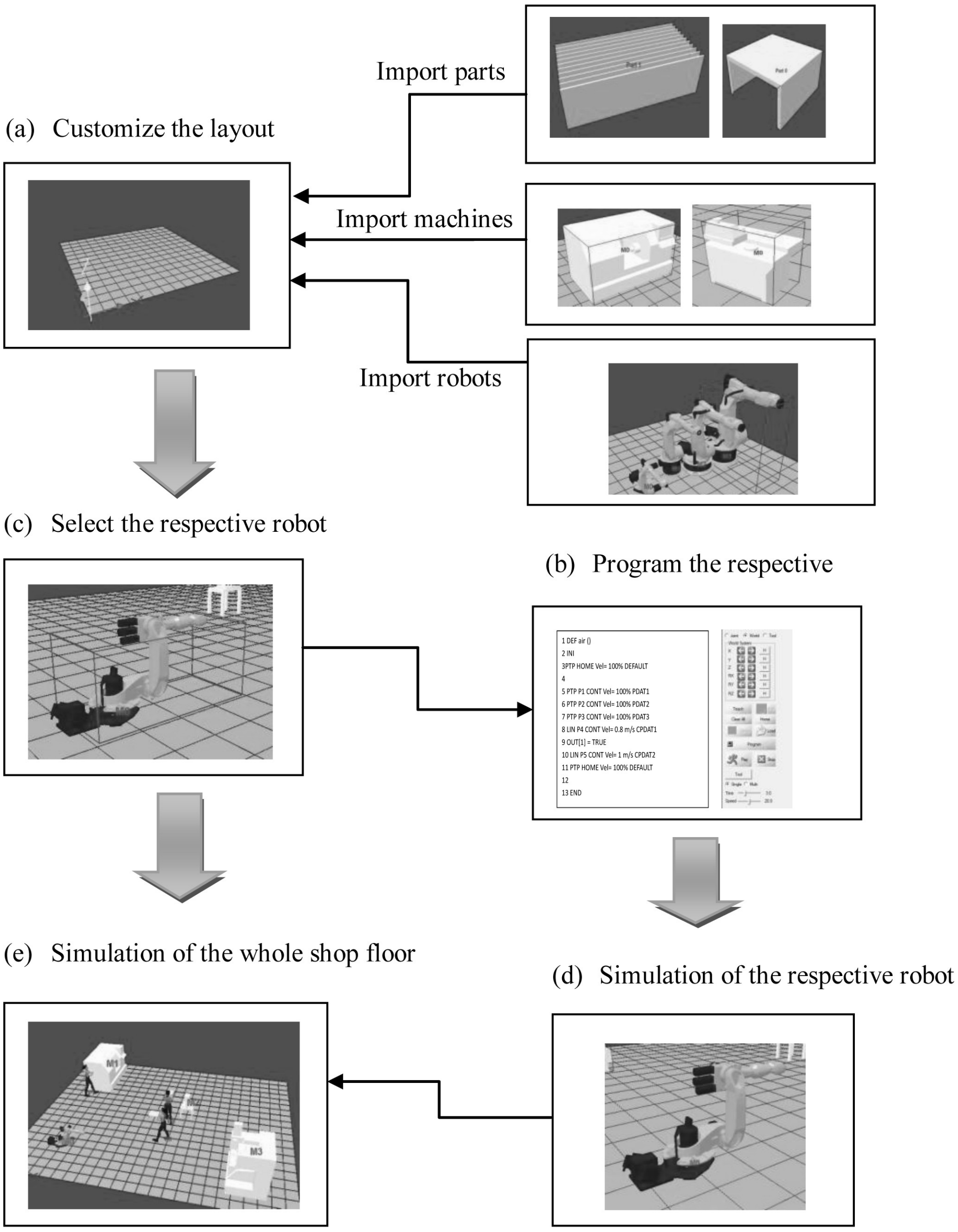
The sample consisted of 114 students, 92 male and 22 female, aged 21–25 years old [mean (M) = 23.46, standard deviation (SD) = 1.29]. The students were undergraduate or fresh graduate students who had attended a formal course on automation and robotics conducted by the department. They had no previous work experience but they possessed strong computer skills. They were proficient in at least one programming language, a CAD program, a CAM program and a Web browsing program. These students were randomly assigned to two groups: the experimental group (n = 60) and control group (n = 54). The experimental group used G-IRSTS and the control group used IRSTS.

2.3 Materials

Two similar simulation tools developed by the researcher were used in this study: a non-gaming conventional robotics simulator (IRSTS) and a constructivist game-based robotics simulator (G-IRSTS).

2.3.1 IRSTS

IRSTS was developed using Visual C++ and OpenGL as its graphic library. The system structure of the IRSTS is presented in Fig. 1. The features of IRSTS cover the whole range of industrial work cell simulation in small and medium size industries (SMI). The training process starts with an empty layout where students can customize the dimension of the layout. This is followed by importing robots, machines and parts to the shop floor. Students can select Kuka robots of different arm dimensions and payloads from the library of IRSTS. In addition, students can also customize their own virtual robot using the Virtual Robot Construction Module of IRSTS. The next step is to create the layout, especially the reachability analysis to determine the robots and their workspaces. Thereafter, the robot program is developed and tested in each work cell. The work is completely carried out in a simulation environment and is based on the defined model of the work cell, without the use of any physical robot. Finally the successful robot program can be downloaded into the physical robot controllers on the shop floor. The software has the capability of simulating the whole process cycle of the shop floor where the different parts are transferred from one machine to another in a process by the opera-



(a) Customize the layout

(b) Program the respective

(c) Select the respective robot

(d) Simulation of the respective robot

(e) Simulation of the whole shop floor

```
DEF air ()
INI
PTP HOME Vel= 100% DEFAULT

PTP P1 CONT Vel= 100% PDAT1
PTP P2 CONT Vel= 100% PDAT2
PTP P3 CONT Vel= 100% PDAT3
LIN P4 CONT Vel= 0.8 m/s CPDAT1
OUT[1] = TRUE
LIN P5 CONT Vel= 1 m/s CPDAT2
PTP HOME Vel= 100% DEFAULT

END
```

Fig. 1. The system structure of IRSTS.

tors. The main goal is a step by step realization of a robot program for different work cells.

2.3.2 G-IRSTS

Several scenarios are customized in G-IRSTS, as shown in Fig. 2. There are some objectives and a series of tasks to be completed by the student in each scenario. Basically, there are two types of games in the early version of G-IRSTS, which are robot welding, pick and place. After choosing the game from the menu, the pre-defined projects are launched from the G-IRSTS instead of an empty layout in IRSTS. Figure 3 shows the game structure of G-IRSTS. If a student chooses robot welding, a work cell is automatically loaded into the layout. The students are required to do a similar task, such as choosing an appropriate robot or customizing a robot, then choose an appropriate tool, program the robot using graphical or text programming and finally run the simulation. The game logic behind each scenario determined the end-state of the simulation. If the mission fails, the student has to repeat that scenario. If the mission is accomplished, points are accumulated and the student can proceed to

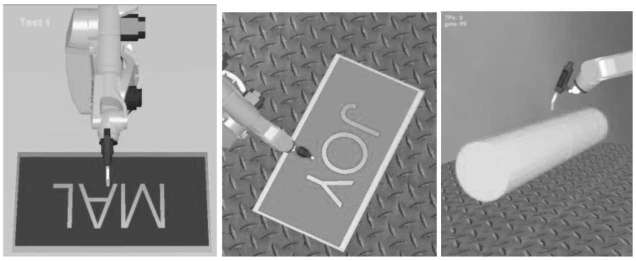


Fig. 2. Different scenarios of robot welding.

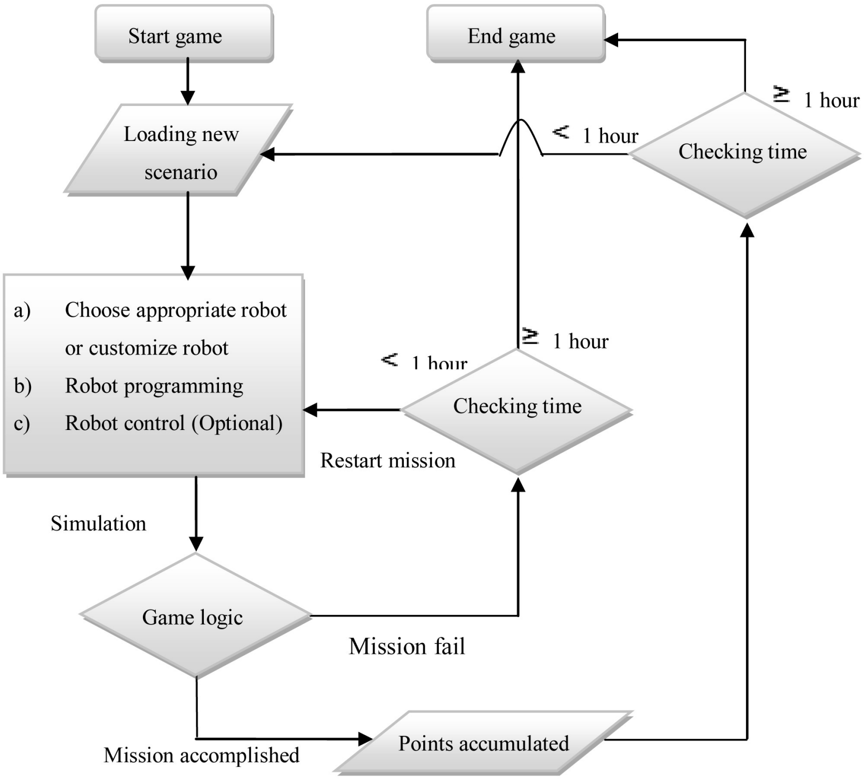


Fig. 3. The game structure of G-IRSTS.

another scenario. Generally, the task of a new scenario would be more complicated and difficult. The game logic consisted of the physics and Artificial Intelligent (AI) system that determines the end-state of each scenario. The physics system is used to detect for collision between objects. The AI of the game logic includes the rule-based system that is used to determine whether the rules are followed in each scenario. The game is stopped after one hour and the accumulated points are shown to the students.

2.4 Questionnaire

There are two questionnaires being designed, modified and used in this study; these are: (a) Constructivist Simulation-based Learning Environment Survey (CSLES) and (b) Test of Robotics Related Attitudes (TORRA).

2.4.1 Constructivist Simulation-based Learning Environment Survey (CSLES)

To assess students' perceptions of the simulation-based learning environment, CSLES was implemented in this study. This questionnaire was slightly modified from the Constructivist Multimedia Learning Environment Survey [26] and Constructivist Internet-based Learning Environment survey [27]. As a result the CSLES consisted of six scales (five items for each scale), presented as Almost Always, Often, Sometimes, Seldom, or Almost Never in a five point Likert scale. Table 1 provided a description of each of these scales together with a

Table 1. Descriptive Information for Each Scale of the CSLES

Scale name	**Description**
Negotiation	Measuring perceptions of the extent to which students have opportunities to explain and modify their ideas to other students in the simulation-based learning environment
Inquiry learning	Measuring perceptions of the extent to which students have opportunities to be engaged in inquiry learning in the simulation-based learning environment
Reflective thinking	Measuring perceptions of the extent to which students have opportunities to exhibit self-reflective thinking in the simulation
Relevance	Measuring perceptions of the extent to which students discern that the simulation-based learning environments are authentic and represent real-life situations
Ease of use	Measuring perceptions of the extent to which students discern that the simulation-based learning environments are easy to use
Challenge	Measuring perceptions of the extent to which students discern that the simulation-based learning environments are challenging but helpful in problem solving

sample item. The completed version of CSLES is listed in the Appendix.

CSLES (similar to CMLES) also consisted of Negotiation, Inquiry Learning and Reflective thinking, which assessed students' perceptions of the constructivist learning process with IRSTS and G-IRSTS respectively. The second part of the questionnaire assessed students' reactions to the IRSTS and G-IRSTS respectively and consisted of three scales of Relevance, Ease of use and Challenge. The CSLES was also administered in two forms: the Actual and Preferred Form, to different groups of students in this research. The Actual Form measured the perception of the actual simulation-based learning environment, while the Preferred Form measured the ideal perception of the simulation-based learning environment. Using both the Actual and Preferred Forms of CSLES allows exploration of whether students achieve better results when there is greater similarity in the actual simulation-based environment to that preferred by the students [28].

2.4.2 Test Of Robotics Related Attitudes (TORRA)

TORRA is used to investigate the students' attitudes toward robotics lessons using simulations in this study. It is modified from the Test Of Science-Related Attitudes (TOSRA). TOSRA was originally designed to measure seven distinct dimensions of science-related attitudes in students in the secondary grades [28]. An attitude scale is considered and modeled in TORRA in this study with one of the seven original scales taken from TOSRA, namely, the Enjoyment of Science Lessons scale. However, to make the scale more suitable for this research, several modifications are made. First, the items are all reworded to measure enjoyment of the robotics lessons using simulation. For instance, an item that read 'I look forward to science lessons' is reworded as 'I look forward to robotics lessons'. Second, the title of the scale is changed to Enjoyment of Robotics Lessons using Simulation. Thirdly, negatively phrased items, such as 'I dislike the lessons', are rephrased in a positive manner, such as 'I like the lessons'. It avoids confusion among the students when responding to the items on the questionnaires. Finally, only 8 out of the 10 items in the Enjoyment of Robotics Lessons using Simulation scale are chosen, as shown in the Appendix.

2.5 Procedure

This study is divided into two groups, the control and the experimental groups. The control group uses IRSTS and the experimental group uses G-IRSTS. To make the learning process more effective, each group is again divided into 6 classes, and around 10 students are assigned to each class. Each class had attended the computer laboratory session accordingly to the time slots given. Each session is conducted by the authors. The data collection procedures on each session start with an overview introduction to either IRSTS or G-IRSTS. This is followed by a series of demonstrations to highlight the important features of the particular simulation tool. Each student is provided with a PC and unlimited time to complete the assignment/challenge. Finally, the procedures end with the questionnaires' administration.

3. Results

3.1 Reliability and factorial validity of CSLES

Factor and item analyses were conducted separately for data collected respectively from the two groups using the Actual and Preferred Forms of CSLES. To determine the factorial validity, principal components factor analysis with varimax rotation was carried out. Since the CSLES was designed with six scales, a six-factor solution was considered. The analysis was conducted in SPSS 18 for Windows and the individual student scores were used as the unit of analysis. The factor loadings, eigenvalues and per-

Table 2. Factor Loadings for Actual (A) and Preferred (P) forms of the simulation-based learning environment scales based on the CSLES for the Control (Con) and Experimental (Exp) group

Item no.	Factor loading																							
	Negotiation				**Inquiry learning**				**Reflective thinking**				**Relevance**				**Ease of use**				**Challenge**			
	Con.		**Exp.**		**Con.**		**Exp.**		**Con.**		**Exp.**		**Con.**		**Exp.**		**Con.**		**Exp.**		**Con.**		**Exp.**	
	A	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**
1	0.72	0.88	0.87	0.79																				
2	0.90	0.94	0.92	0.83																				
3	0.83	0.81	0.89	0.77																				
4	0.61	0.88	0.87	0.89																				
5	0.70	0.77	0.93	0.89																				
6					0.67	0.89	0.92	0.94																
7					0.68	0.57	0.92	0.93																
8					0.91	0.71	0.90	0.94																
9					0.77	0.94	0.87	0.93																
10					0.91	0.94	0.88	0.93																
11									0.68	0.78	0.82	0.87												
12									0.86	0.87	0.82	0.85												
13									0.86	0.83	0.80	0.88												
14									0.73	0.86	0.65	0.84												
15									0.57	0.88	0.80	0.87												
16													0.83	0.65	0.69	0.83								
17													0.95	0.92	0.84	0.95								
18													0.72	0.90	0.79	0.95								
19													0.95	0.91	0.81	0.96								
20													0.93	0.88	0.88	0.93								
21																	0.89	0.92	0.88	0.93				
22																	0.78	0.90	0.86	0.95				
23																	0.88	0.91	0.83	0.94				
24																	0.89	0.91	0.87	0.61				
25																	0.65	0.78	0.88	0.87				
26																					0.96	0.89	0.90	0.87
27																					0.93	0.92	0.91	0.92
28																					0.96	0.90	0.92	0.94
29																					0.93	0.83	—	0.96
30																					0.96	0.84	0.90	0.93
%v	17.1	15.4	15.9	16.9	14.4	15.0	14.9	15.6	14.3	15.0	14.8	15.4	13.1	14.5	14.5	13.7	12.0	13.4	12.9	13.6	10.8	12.4	12.7	13.6
E	5.14	4.61	4.78	5.07	4.31	4.5	4.46	4.67	4.29	4.49	4.43	4.62	3.94	4.36	4.36	4.1	3.61	4.02	3.88	4.09	3.23	3.72	3.81	4.08

centage of variance of each simulation-based learning environment scale were reported separately for the two groups using Actual and Preferred Forms of CSLES in Table 2. Items were referred to by numbers, while the actual wording of the items can be found in the Appendix.

In a previous research [26] the criteria used to retain an item were that it must have a factor loading of 0.40 and above with its *a priori* scale and below 0.40 with each other scale. As shown in Table 2, the factor analysis in the CSLES questionnaire demonstrated a strong consistency in factor structure. The *a priori* six-scale structure was replicated almost perfectly in both groups in that nearly all the items have a factor loading of at least 0.40 on their own scale and less than 0.40 on other scales. The only exception was that one item (item 29) of the Challenge scale for the Actual Form of the experimental group did not have a factor loading above 0.40 on its own scale. Item 29 of the Actual Form was removed and it was excluded from subsequent analyses. As one item was removed, only 29 items remain in the following discussions.

In the control group, the percentage of variance of the Actual Form ranges from 10.76% to 17.14%, with a total of 81.74% variance for all the six scales combined. The eigenvalues for the six scales range from 3.22 to 5.14 for the Actual Forms. Meanwhile, the percentage of variance of the Preferred Form ranges from 12.41% to 15.37%, with a total of 85.66%. The eigenvalues for the Preferred Form range from 3.72 to 4.61. In the experimental group, the percentage of variance of the Actual Form ranges from 12.71% to 15.93%. Even with the minor discrepancy of the Challenge scale, the six scales together accounted for nearly 85.74% of variance. The eigenvalues for the six scales range from 3.81 to 4.78 for the Actual Form. Meanwhile, the percentage of variance of the Preferred Form ranges from 13.61% to 16.89%, with a total variance of 88.73%. The eigenvalues for the Preferred Form range from 4.08 to 5.07.

Overall, the percentage of variance and eigenvalue results shown in Table 2 suggests that the questionnaire containing simulation-based learning environment scales based on the CSLES has a similar factor structure when used with either the Actual or Preferred Form in the two groups. These results give a strong signal that the factor structure of the scales is clear and repeatable. The corroboration of the factor loadings, eigenvalues, and percentage of variance gives confidence in the power of the CSLES questionnaire to measure the students' actual and preferred simulation-based environment of the two groups.

3.2 Reliability and factorial validity of TORRA

Principal component factor analysis was also performed for both control and experimental groups, respectively, to confirm the *a priori* structure of the Test of Robotics Related Attitudes (TORRA). TORRA comprised 8 items in one scale of Enjoyment of Robotics Lessons using Simulation. This analysis is performed to identify faulty items that could be removed in order to improve the factorial validity of an attitude scale of TORRA in the control and experimental group respectively. As shown in Table 3, the factor analysis of the 8 items in the TORRA also demonstrates a strong factor structure to be consistent in both control and experimental groups. The totals of variance are 63.04% and 85.40% for the control and experimental groups, respectively. The eigenvalues are 5.04% and 6.83% for the control and experimental groups respectively. The corroboration of the factor loadings, eigenvalues, and percentage of variance gives confidence in the power of one scale TORRA questionnaire to measure the students' attitudes in both groups.

3.3 Internal consistency reliability

To check whether every item in each scale assessed a similar construct, the internal consistency reliability was used. The index of scale internal consistency used is a Cronbach alpha coefficient. Table 4 shows the Cronbach alpha coefficient for each scale based on the CSLES (Actual and Preferred Forms) and one attitude scale based on the TORRA separately for the control and experimental groups.

When using the individual student scores as the unit of analysis in the control group, the alpha coefficients for the six different scales ranges from 0.84 to 0.98 for the Actual Form and from 0.90 to 0.96 for the Preferred Form. In the experimental group, the alpha coefficients for the six different scales range from 0.92 to 0.98 for the Actual Form and from 0.93 to 0.99 for the Preferred Form when using the individual student scores as the unit of analysis. The alpha reliability coefficients for all scales are very high and all exceeded 0.80. These coefficients are similar for both the Actual and Preferred Forms of CSLES in the two groups. This suggests that all scales of CSLES are reliable when used to measure students' perceptions of both the Actual and Preferred Forms in the control and experimental group.

The bottom of Table 4 shows the alpha coefficients of an attitude scale of TORRA. The alpha coefficients are 0.89 and 0.97 for the control and experimental groups respectively when using the individual student scores as the unit of analysis. The high Alpha Coefficients indicate a reliable TORRA questionnaire with a strong level of internal consistency in the control and experimental groups.

3.4 Discriminant validity

To check whether each of the simulation-based learning environment scales measured a distinct construct, the discriminant validity was calculated for each of the six scales. The mean correlation of a scale with other scales is a convenient index used to determine discriminant validity. Table 5 shows the discriminant validity for a simulation-based learning environment on the CSLES using individual scores as the unit of analysis for the control and experimental groups respectively.

In the control group, the mean correlation of a

Table 3. Factor loadings for an attitude scale based on the TORRA (Enjoyment of Robotics Lessons using simulation) for the control and experimental group

	Factor loading	
Item no.	**Control group**	**Experimental group**
1	0.93	0.96
2	0.72	0.98
3	0.93	0.85
4	0.66	0.97
5	0.72	0.96
6	0.71	0.81
7	0.71	0.89
8	0.93	0.95
% Variance	63.04%	85.40%
Eigenvalue	5.04	6.83

Table 4. Internal consistency (Cronbach Alpha Coefficient) for simulation-based learning environment scales based on CSLES and an attitude scale based on TORRA for the control and experimental group

	Alpha reliability			
	Control		Experimental	
Scale	**Actual**	**Preferred**	**Actual**	**Preferred**
Negotiation	0.84	0.93	0.95	0.94
Inquiry learning	0.93	0.90	0.98	0.99
Reflective thinking	0.88	0.94	0.92	0.94
Relevance	0.94	0.95	0.94	0.96
Ease of use	0.94	0.96	0.96	0.93
Challenge	0.98	0.96	0.98	0.97
Attitude	0.89	–	0.97	–

Table 5. Discriminant validity (mean correlation with other scales) for simulation-based learning environment scales based on the CSLES for the control and experimental groups

	Mean correlation with other scales			
	Control		Experimental	
Scale	Actual	Preferred	Actual	Preferred
Negotiation	0.25	0.29	0.02	0.45
Inquiry learning	0.56	0.30	0.46	0.27
Reflective thinking	0.59	0.43	0.60	0.23
Relevance	0.27	0.48	0.65	0.23
Ease of use	0.56	0.43	0.51	0.24
Challenge	0.35	0.51	0.41	0.24

scale with other scales ranges from 0.25 to 0.59 for the Actual Form and from 0.29 to 0.51 for the Preferred Form. In the experimental group, the mean correlation of a scale with other scales ranges from 0.02 to 0.65 for the Actual Form and from 0.23 to 0.45 for the Preferred Form when using the individual student scores as the unit of analysis. The discriminant validity (the mean correlation of a scale with other scales) is less than 0.70 in each scale for the two groups. These results indicate that most scales are fairly unique in the dimension that each assessed. Although there are some overlaps between scores, the factor analysis results support the independence scores as discussed in the above sections [29–30].

3.5 Differences between undergraduate students' perceptions of actual and preferred simulation-based learning environment in the experimental group

To explore the differences between students' perceptions of the actual simulation-based environment compared with the preferred simulation-based learning environment, the average item mean is determined. Using the individual as the unit of analysis, effect sizes are calculated to determine the magnitude of the difference between actual and preferred perceptions. The analysis involves a series of t-tests for pair samples from the Actual and Preferred Form with repeated measures of each scale.

Table 6 shows the differences in students' perceptions of the actual and preferred simulation-based learning environment in the two groups. T-test results revealed statistically significant ($p < 0.01$) results overall for each repeated measures interpreted for each scale. The effect sizes ranges from 1.54 to 2.08 in the control group and ranges from 1.14 to 2.26 in the experimental group. Of particular note are the larger effect sizes in the control group when compared with the experimental group. The only exceptional scale was Inquiry learning in the experimental group, which had the largest effect size (effect size 2.26) in the two groups.

3.6 Differences between the control and experimental group in terms of actual and preferred scores on the CSLES and TORRA

To explore the differences between the control and experimental group in terms of actual and preferred simulation-based environment and attitudes toward robotics lessons using simulation, the average item mean was calculated for each scale of CSLES and an attitude scale of TORRA. Using the individual as the unit of analysis, the effect sizes were calculated to determine the magnitude of the scores differences between the control and experimental group. All analyses were performed separately for the Actual and Preferred Forms of CSLES and an attitude scale of TORRA as in Table 7.

T-test results as shown in Table 7 indicate that four of the six scales of Actual Form in CSLES are

Table 6. Average item means, average item standard deviations and differences between actual and preferred forms of simulation-based learning environment scales based on the CSLES of the control and experimental group

		Mean		Standard deviation		Difference	
Scale	Group	Actual	Preferred	Actual	Preferred	Effect size	*t*
Negotiation	Control	3.21	4.36	0.76	0.70	1.57	9.64**
	Experimental	3.54	4.42	0.57	0.64	1.45	8.51**
Inquiry learning	Control	2.89	4.30	0.82	0.54	2.03	14.34**
	Experimental	3.24	4.55	0.59	0.57	2.26	13.42**
Reflective thinking	Control	3.06	4.20	0.71	0.60	1.73	9.92**
	Experimental	3.55	4.19	0.56	0.56	1.14	7.27**
Relevance	Control	3.28	4.34	0.68	0.70	1.54	11.61**
	Experimental	3.44	4.39	0.83	0.65	1.27	7.89**
Ease of use	Control	3.29	4.59	0.64	0.61	2.08	11.01**
	Experimental	3.31	4.42	0.64	0.56	1.84	11.82**
Challenge	Control	3.09	4.44	0.91	0.59	1.76	9.87**
	Experimental	3.73	4.47	0.74	0.55	1.14	5.91**

**$p < 0.01$.

Table 7. Average item means, average item standard deviations and differences between Control (Con) and Experimental (Exp) group in Actual and Preferred forms of simulation-based learning environment scales based on the CSLES and an attitude scale based on TORRA

		Mean		**Standard deviation**		**Difference**	
Scale	**Form**	**Con.**	**Exp.**	**Con.**	**Exp.**	**Effect size**	***t***
Negotiation	Actual	3.21	3.54	0.76	0.57	0.49	2.79**
	Preferred	4.36	4.42	0.70	0.64	0.09	–0.04
Inquiry learning	Actual	2.89	3.24	0.82	0.59	0.49	3.22**
	Preferred	4.30	4.55	0.54	0.57	0.45	3.25**
Reflective thinking	Actual	3.06	3.55	0.71	0.56	0.77	4.64**
	Preferred	4.20	4.19	0.60	0.56	0.02	–0.47
Relevance	Actual	3.28	3.44	0.68	0.83	0.21	1.48
	Preferred	4.34	4.39	0.70	0.65	0.07	0.25
Ease of use	Actual	3.29	3.31	0.64	0.64	0.03	0.37
	Preferred	4.59	4.42	0.61	0.56	0.29	–2.19*
Challenge	Actual	3.09	3.73	0.91	0.74	0.77	4.28**
	Preferred	4.44	4.47	0.59	0.55	0.05	0.31

**$p < 0.01$, *$p < 0.05$.

statistically significance ($p < 0.01$). Relevance and Ease of use are the only two scales that do not reveal statistically significant differences. Negotiation (effect size 0.49), Inquiry Learning (effect size 0.49), Reflective Thinking (effect size 0.77) and Challenge (effect size 0.77) are found to have moderate effect sizes and thereby reflected the effectiveness of implementation of the game elements in the G-IRSTS on the four scales. In contrast, the differences between what students from the control group and students from the experimental group would prefer happening in their simulation-based environment are generally small. Only Inquiry Learning (effect size 0.45, $p < 0.01$) and Ease of use (effect size 0.29, $p < 0.05$) exhibited statistically significant differences between the two groups with moderate effect sizes. The students in the experimental group preferred a greater level of Inquiry Learning. On the other hand, undergraduate students in the control group preferred a greater level of Ease of use.

Figure 4 graphically illustrates the item mean averages for differences scales in the control group and the experimental group in their actual CSLES scores and the TORRA scores. Consistent with the above results, students in the experimental group scored higher in all six scales of CSLES and an attitude scale of TORRA. Nevertheless, Relevance and Ease of use of CSLES and the attitude scale did not exhibited statistically significant differences between the two groups as shown in Table 6.

3.7 Associations between students' perceptions of simulation-based learning environment and enjoyment of robotics lessons using simulations

Associations between simulation-based learning environment scales and the attitude scale were investigated through simple correlation and multiple regression analyses with the simulation-based learning environment scales of CSLES serving as independent variables and the attitude scale of

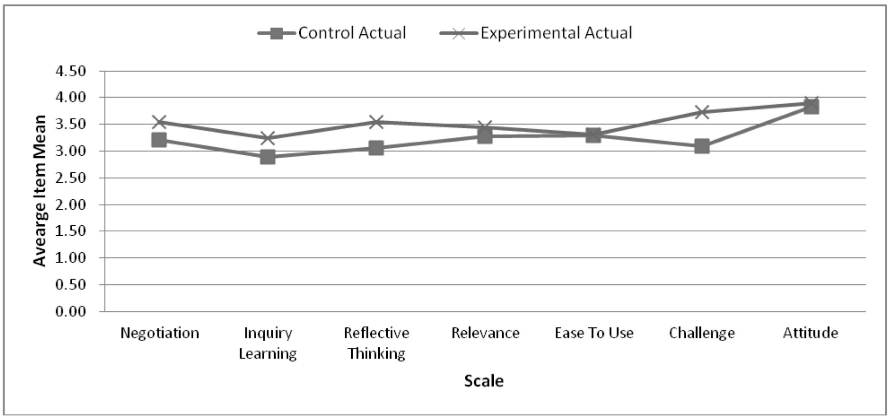


Fig. 4. Comparison of average item means between control and experimental groups for the actual forms of simulation-based learning environment scales based on the CSLES and an attitude scale based on TORRA.

Table 8. Simple correlation and multiple regression analyses for associations between attitude and learning environment for the control and experimental group

	Control		Experimental	
Scale	**Simple correlation (r)**	**Standardized regression (β)**	**Simple correlation (r)**	**Standardized regression (β)**
Negotiation	0.19	0.15	–0.21	–0.20
Inquiry learning	0.13	0.00	0.23	–0.13
Reflective thinking	0.11	0.10	0.41**	0.28
Relevance	–0.86	–0.10	0.52**	0.57**
Ease of use	0.05	0.01	0.10	–0.16
Challenge	0.07	–0.05	0.10	–0.12
Multiple correlation	–	0.07	–	0.40**

TORRA (Enjoyment of Robotics' Lessons using Simulations) as the dependent variable. The correlation analysis involved simple Pearson product–moment correlations, which identify the bivariate relationship between the attitude scale and each simulation-based learning environment scale. Also, a multiple regression analysis was conducted for the attitude scale. This analysis identified the relationship of the attitude scale as a dependent variable with the set of simulation-based learning environment scales as independent variables. In particular, the regression coefficient indicates the unique contribution made by a specific learning environment dimension in expanding the variance in the dependent variable when all the learning scales are mutually controlled [29–30]. The simple correlation and multiple analysis were carried in the section were used individuals as the unit of analysis as shown in Table 8.

The attitude scale (Enjoyment of Robotics' Lessons using Simulations) shows no significant relationships with the simulation-based learning environment scales for either the simple correlation or multiple regression analyses in the control group. The multiple correlation score between the attitude scale and the set of CSLES scales is very low (R = 0.07) and is not statistically significant. It appears that specific emphasis in the simulation-based learning environment in the control group did not contribute to the attitude (Enjoyment of Robotics' Lessons using Simulations). The undergraduate students' enjoyment of robotics' lessons using simulation in the control group was probably not as dependent on the simulation-based learning environment.

The simple correlation analysis of associations between the attitude towards robotics lessons using simulations and the simulation-based learning environment scales yielded some interesting findings. There are two scales with significant simple correlations with the factor of Enjoyment of Robotics' Lessons using Simulations. There are Reflective thinking (r = 0.41) and Relevance (r = 0.52). The strongest correlation between attitudes and the simulation-based learning environment is Relevance. Because all significant correlations are positive, this suggests a direct relationship between students' enjoyment of robotics lessons using simulations and the two scales of CSLES. The multiple correlation score between the attitude scale and the set of CSLES scales is 0.40 and is statistically significant ($p < 0.01$). Inspection of the regression coefficient in Table 7 shows that Relevance is significantly ($p < 0.01$), positively related to Enjoyment of Robotics Lessons using Simulations when all the other simulation-based learning environment scales are mutually controlled.

4. Discussions

The main aim of this paper is to investigate the learning environment of a constructivist game-based robotics simulator (G-IRSTS) in a manufacturing course, as compared with a similar (non-gaming) conventional robot simulator (IRSTS). The learning environment is measured in terms of the students' perceptions of the simulation-based environment and their attitudes toward robotics lessons using simulation. The analysis presented in Section 3.6 found that the Game-based Robotics Simulator (G-IRSTS) is more effective for students than the non-gaming simulator (IRSTS) in terms of Negotiation, Inquiry Learning, Reflective Thinking and Challenge.

As discussed in Section 2.3, various scenarios are implemented in G-IRSTS. These scenarios are based on some missions or goals oriented. Every scenario has some objectives and a series of tasks to be completed by students. There are different rules to be followed. These scenarios introduced conflicts or obstacles that prevent students from reaching their goals easily. Conflicts also included the notions of struggle, competition and challenge. These attributes always engage students, make learning fun, encourage dialogue between students and motivate students to maintain their gaming role or proceed to the next stage or different scenarios. The more stages or scenarios completed, the more points would be rewarded. The attributes are called the game elements. From the above analysis, it can be concluded that the game attributes have played important roles in enhancing the effectiveness in the four scales of the simulation-based learning environment.

The three scales of Negotiation, Inquiry Learning and Reflective thinking, were originally described in [26]. These scales aimed to assess the students' learning process using a constructivist approach within a multimedia program. As deduced from the above analysis, the game element considerably improved constructivist learning using G-IRSTS. It can thus be concluded that a constructivist game-based robotics simulator can be exploited as a learning tool within the engineering education. Those findings seem to support the outcomes of certain prior studies [31] in which games contributed to increased academic achievement compared with traditional teaching in various areas.

The effect sizes for actual-preferred differences of the control group are relatively larger than the experimental group. The effect sizes have implication for both designers of educational software and researchers. It indicated G-IRSTS is closer to the preference of the students if compared with IRSTS. It is interesting that Inquiry Learning in the experimental group is exceptional and its actual-preferred difference was relative large. Inquiry Learning measures the perceptions of the extent to which students have opportunities to be engaged in Inquiry Learning in the simulation-based learning environment. For example, a student could find out answers to questions by investigation, carry out investigations to test their idea, design their own way to investigate a problem or approach a problem from more than one perspective. Since G-IRSTS has been structured in a game format, students have to follow the scenarios customized or developed by the researcher. So, there has provided to be limited flexibility for students to build their virtual shop floor or test their ideas. Therefore, students preferred a higher Inquiry Learning in the experimental group.

Correlation and multiple regression analysis in Section 3.7 seem to suggest that the simulation-based learning environment did not play a role in the students' enjoyment of robotics lessons using simulation in the control group. But it is found that the scale of Relevance is related to the students' enjoyment of robotics lessons using simulation in the experimental group. This would suggest that undergraduate students perceived more relevance in their simulation-based learning environment with gaming elements, which provided them with a complex real-life, meaningful and relevant virtual shop floor, which they enjoyed, and therefore put more effort into their learning.

5. Conclusions

A Constructivist Game-based Robotics Simulator (G-IRSTS) and a conventional non-gaming simulator (IRSTS) were developed in this research. Both have the same contexts, learner specifications and pedagogic considerations but differ from each other in the mode of representations (the game structures). The constructivist game-based robotics simulator can be exploited as a learning tool within engineering education. It was demonstrated to be more effective than the non-gaming simulator in terms of Negotiation, Inquiry Learning, Reflective Thinking and Challenge. The game attributes were believed to have played important roles in enhancing the learning effectiveness of these scales. There was no relationship found between undergraduate students' enjoyment of robotics lessons using simulation and the simulation-based learning environment in the control group. There is positive but relatively weak relationship between the undergraduate students' enjoyment of robotics lessons and the simulation-based learning environment (especially on Relevance) in the experimental group.

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Appendix

Constructivist Simulation-based Learning Environment Survey (CSLES)

Negotiation

	In the simulation-based learning environment, I find that. . .	Almost never	Seldom	Sometimes	Often	Always
1	I get the chance to talk to other students	☐	☐	☐	☐	☐
2	I discuss with other students	☐	☐	☐	☐	☐
3	I can ask other students to explain their ideas	☐	☐	☐	☐	☐
4	Other students can ask me to explain my ideas	☐	☐	☐	☐	☐
5	Other students discuss their ideas with me	☐	☐	☐	☐	☐
Inquiry learning						
6	I can find out the answers to questions by investigation	☐	☐	☐	☐	☐
7	I can carry out investigations to test my own ideas	☐	☐	☐	☐	☐
8	I can conduct follow-up investigations to answer my new questions	☐	☐	☐	☐	☐
9	I can design my own ways of investigating problems	☐	☐	☐	☐	☐
10	I can approach a problem from more than one perspective	☐	☐	☐	☐	☐
Reflective thinking						
11	I can think deeply about how I learn	☐	☐	☐	☐	☐
12	I can think deeply about my own ideas	☐	☐	☐	☐	☐
13	I can think deeply about my new ideas	☐	☐	☐	☐	☐
14	I can think deeply how to become a better learner	☐	☐	☐	☐	☐
15	I can think deeply about my own understanding	☐	☐	☐	☐	☐

Relevance When navigating in the simulation-based learning environments, I find that it. . .	Almost Never	Seldom	Sometimes	Often	Always
16 Shows how complex real-life environment are	☐	☐	☐	☐	☐
17 Presents data in meaningful ways	☐	☐	☐	☐	☐
18 Presents information that is relevant to me	☐	☐	☐	☐	☐
19 Presents realistic tasks	☐	☐	☐	☐	☐
20 Has a wide range of information	☐	☐	☐	☐	☐
Ease of use					
21 Has interesting screen designs	☐	☐	☐	☐	☐
22 Is easy to navigate	☐	☐	☐	☐	☐
23 Is fun to use	☐	☐	☐	☐	☐
24 Is easy to use	☐	☐	☐	☐	☐
25 Takes only a short time to learn to use	☐	☐	☐	☐	☐
Challenge					
26 Makes me think	☐	☐	☐	☐	☐
27 Is complex but clear	☐	☐	☐	☐	☐
28 Is challenging to use	☐	☐	☐	☐	☐
29 Helps me to generate new ideas	☐	☐	☐	☐	☐
30 Helps me to generate new questions	☐	☐	☐	☐	☐

Test Of Robotics Related Attitudes (TORRA)

Enjoyment of the robotics lessons using simulation	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
1 Robotics lessons using simulation are fun	☐	☐	☐	☐	☐
2 I like the robotics lessons using simulation	☐	☐	☐	☐	☐
3 The department should have more simulation lessons like this one	☐	☐	☐	☐	☐
4 The robotics is one of the most interesting subjects	☐	☐	☐	☐	☐
5 I really enjoy going to this robotics class using simulation	☐	☐	☐	☐	☐
6 The simulation software covered in this robotics class is interesting	☐	☐	☐	☐	☐
7 I look forward to robotics class using simulation	☐	☐	☐	☐	☐
8 I would enjoy school more if there were more simulations in robotics like this one	☐	☐	☐	☐	☐

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